



X-48B Flight Research Progress Overview

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Fundamental Aeronautics Program

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Program Objectives

- Assess stability & control characteristics of a BWB class vehicle in free-flight conditions:
 - Assess dynamic interaction of control surfaces
 - Assess control requirements to accommodate asymmetric thrust
 - Assess stability and controllability about each axis at a range of flight conditions
- Assess flight control algorithms designed to provide desired flight characteristics:
 - Assess control surface allocation and blending
 - Assess edge of envelope protection schemes
 - Assess takeoff and landing characteristics
 - Test experimental control laws and control design methods
- Evaluate prediction and test methods for BWB class vehicles:
 - Correlate flight measurements with ground-based predictions and measurements



SFW System Level Metrics

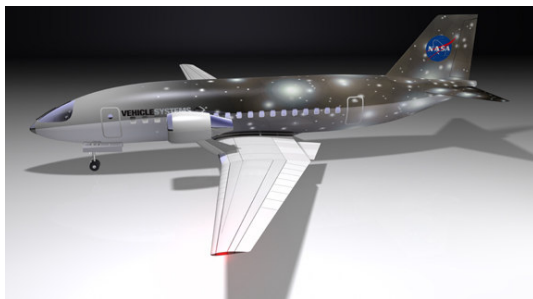
| CORNERS OF THE TRADE SPACE | N+1 (2015 EIS) Generation Conventional Tube and Wing (relative to B737/CFM56) | N+2 (2020 IOC) Generation Unconventional Hybrid Wing Body (relative to B777/GE90) | N+3 (2030-2035 EIS) Generation Advanced Aircraft Concepts (relative to user defined reference) |
|-------------------------------------|---|---|---|
| Noise | - 32 dB (cum below Stage 4) | - 42 dB (cum below Stage 4) | 55 LDN (dB) at average airport boundary |
| LTO NOx Emissions (below CAEP 6) | -60% | -75% | better than -75% |
| Performance: Aircraft Fuel Burn | -33%** | -40%** | better than -70% |
| Performance: Field Length | -33% | -50% | exploit metro-plex* concepts |

** An additional reduction of 10 percent may be possible through improved operational capability

* Concepts that enable optimal use of runways at multiple airports within the metropolitan areas

EIS = Entry Into Service; IOC = Initial Operating Capability

N+1 Conventional



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N+2 Hybrid Wing/Body



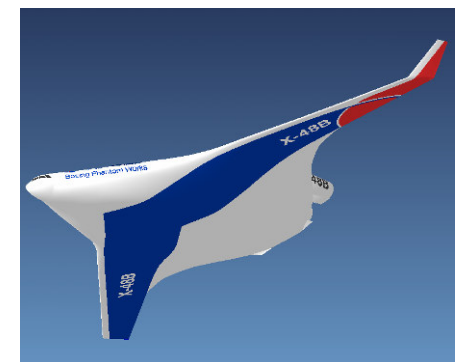
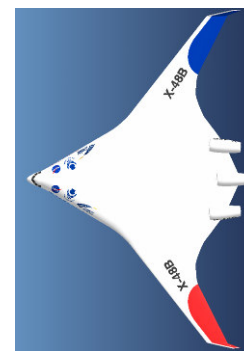
N+3 Generation





X-48B Flight Research Program

- Flight research provides:
 - Flight Control System risk reduction
 - Required to ensure HWB configuration is as safe as a conventional airplane
- Investigate:
 - Stall Characteristics
 - Departure Onset Boundaries
 - Asymmetric Thrust Control
 - Flight Control Algorithms
 - Envelope Protection Schemes
 - Dynamic Ground Effects
 - Control Surface Hinge Moments





Major Program Accomplishments

- 30 successful flights including 2 flights in 1 day four times
- Completion of envelope expansion phases in both slats extended and slats retracted configurations
- Aircraft capable of operating from hard surface and lakebed runways at Dryden
- Both Boeing and NASA pilots trained to fly aircraft and first NASA pilot mission flown on 8/13/08
- High quality data for various maneuvers recorded and archived for future use
- Preliminary data analysis ongoing with quick look data report for first 20 flights available before end of year
- Five high AOA flights performed and stable AOA limit found
- Multiple versions of software upgrades performed resulting in stable test platform
- Significant positive press coverage of flight test including articles in *Aviation Week and Space Technology*, *Popular Science*, *Outside*, *Aviation/Yahoo*, *AeroTech News*



Definition of Test Flight Blocks

March 1, 2008

Departure Limiter
Assaults

Block 6: Flights 36-40
Slats RET – S/W VX.X

Block 5: Flights 31-35
Slats EXT – S/W VX.X

November 30, 2008

PID / Stalls /
Engine Out
Maneuvering

Block 4: Flights 26-30
Slats RET – S/W V3.X

Block 3: Flights 21-25
Slats EXT – S/W V3.X

Current
Phase

July 25, 2008

Envelope Expansion

Block 2: Flights 12-20
Slats RET – S/W V3.2.4.0

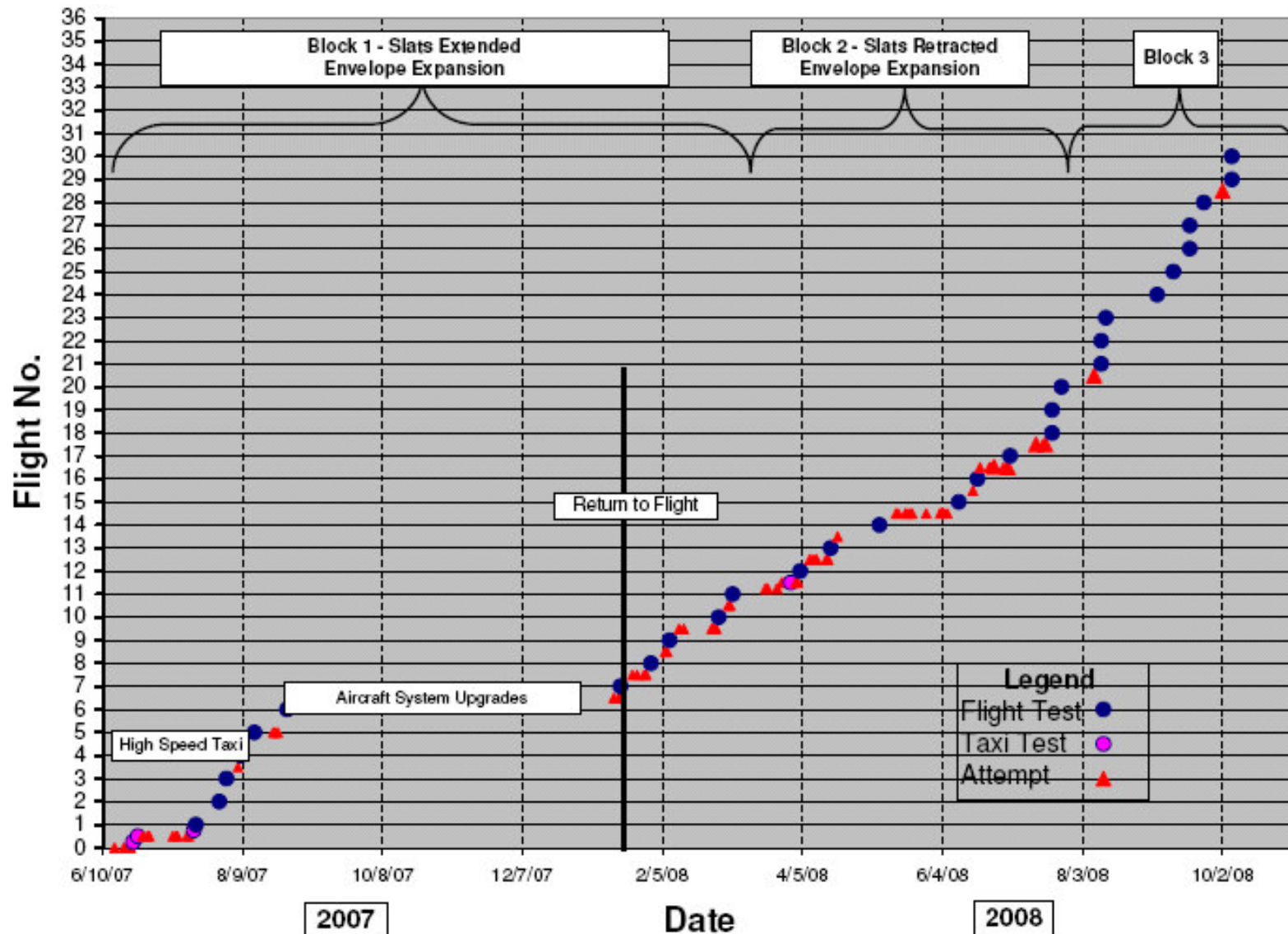
Block 1: Flights 1-11
Slats EXT – S/W V2.1.4.2

Increasing Risk

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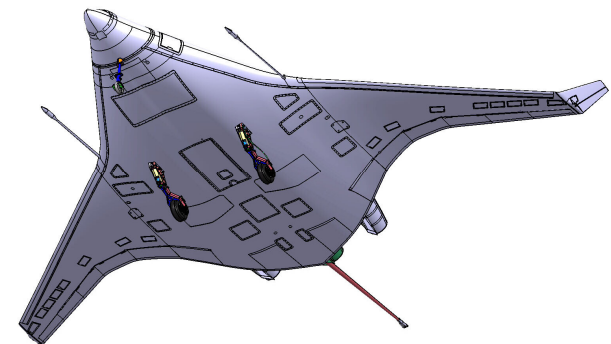
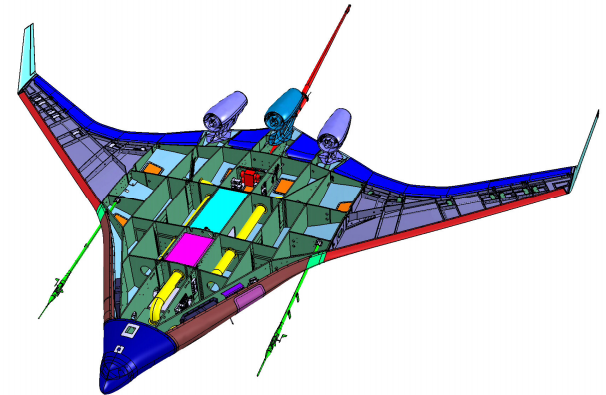
Flight Test Progress





X-48B BWB Low Speed Vehicle

- Two X-48B Aircraft and Ground Control Station (GCS)
 - Research Partnership of Boeing, NASA, and AFRL
 - Design and fabrication contracted to Cranfield Aerospace
- Air Vehicle Highlights:
 - Dynamically Scaled
 - Uninhabited Air Vehicle
 - Flown by Pilot from Ground Station
 - Powered by 3 Small Turbojets
 - Ground Start only
 - Conventional takeoff and landing
 - Non-retractable Tricycle Gear
 - Slats are Fixed for either Extended or Retracted
 - Recovery System
 - Drogue, Parachute, and Air Bags





X-48B Vehicle

- Design Approach

- Use low cost (COTS) equipment where possible
 - Engines - JetCat P200
 - Landing Gear - mountain bike shocks & brakes
- Use normal industry practice for electronic equipment
- Use aircraft spec equipment where necessary
 - Radios, IMU, Actuators, Flight Termination System (FTS) parts
- Save weight to meet dynamic scaling requirements



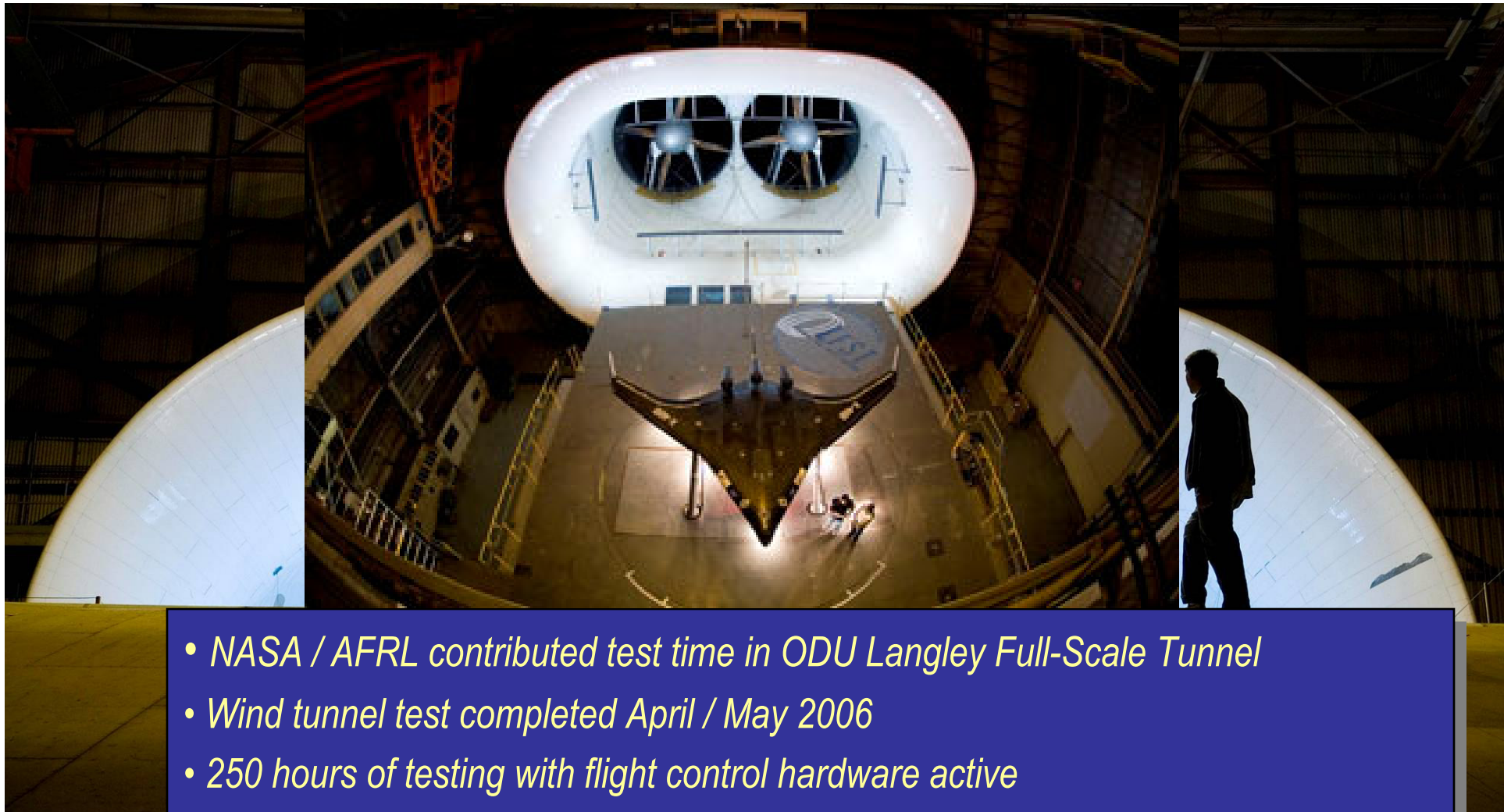
JetCat P200 Engines



Nose & Main Landing Gear



X-48B 30x60 Wind Tunnel Test



- *NASA / AFRL contributed test time in ODU Langley Full-Scale Tunnel*
- *Wind tunnel test completed April / May 2006*
- *250 hours of testing with flight control hardware active*
- *Data used by Boeing for X-48B simulation and flight control software*



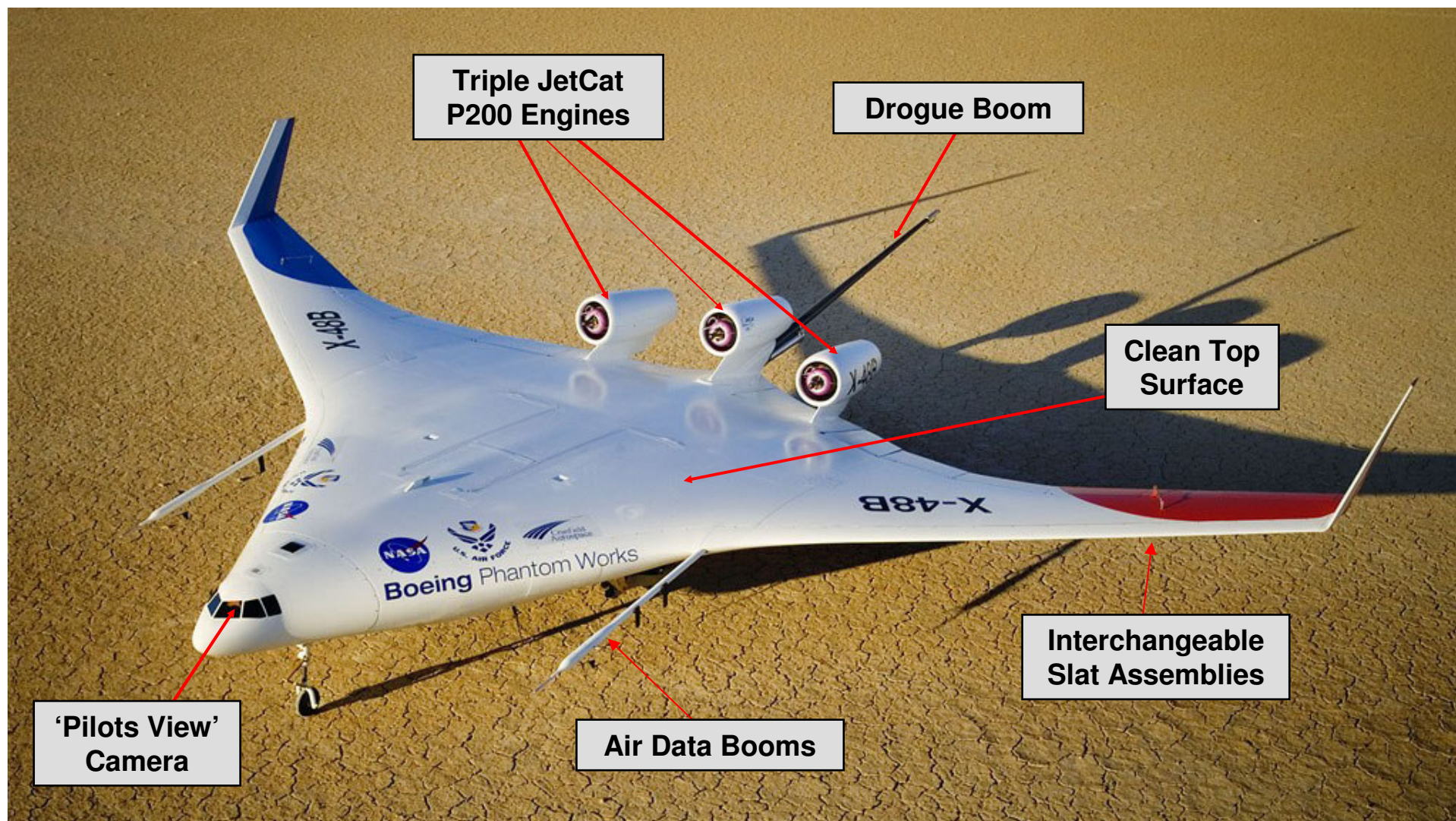
8.5% Dynamically Scaled X-48B



Subsonic Fixed Wing Project

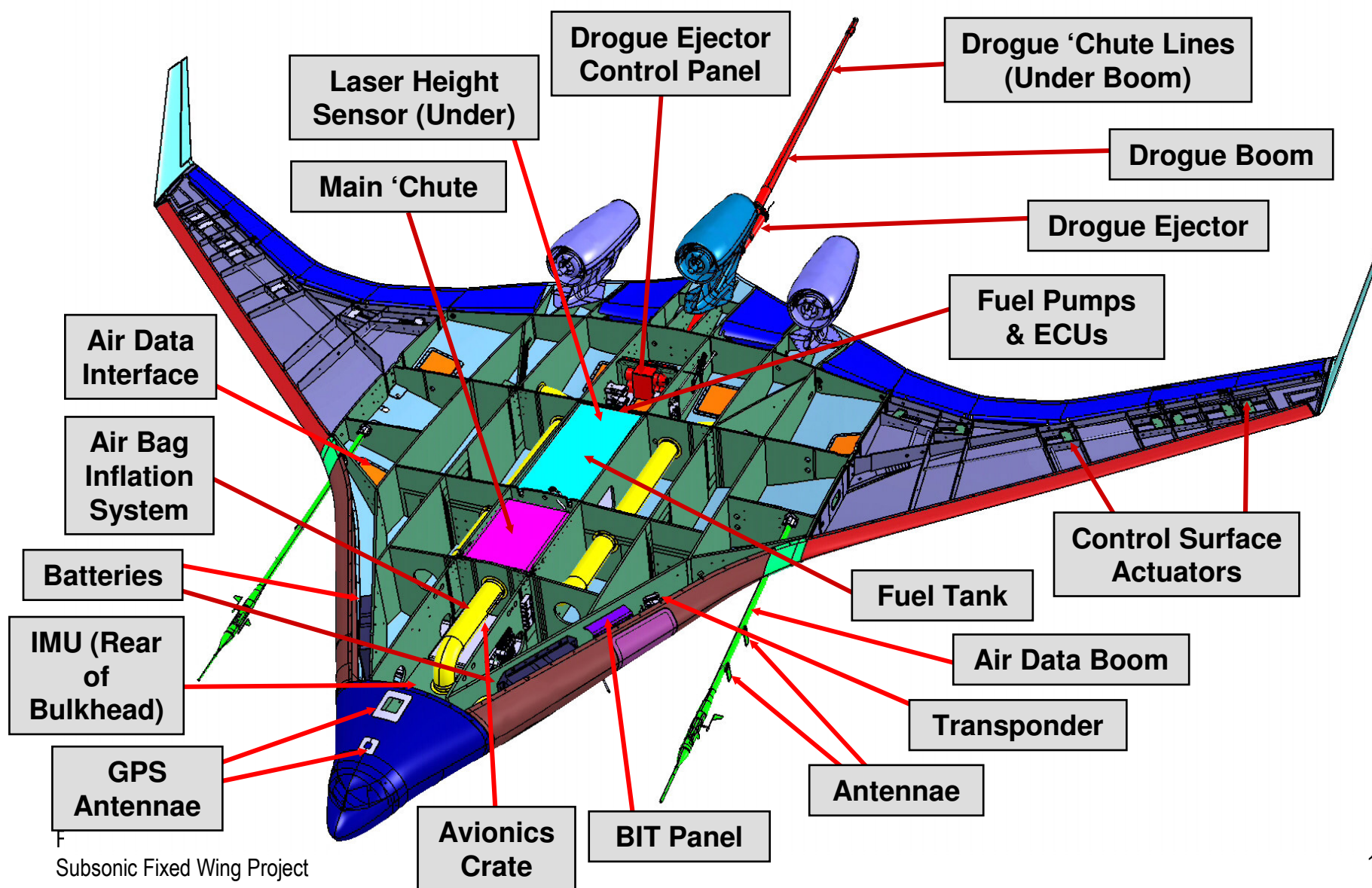


X-48B Configuration – Top View



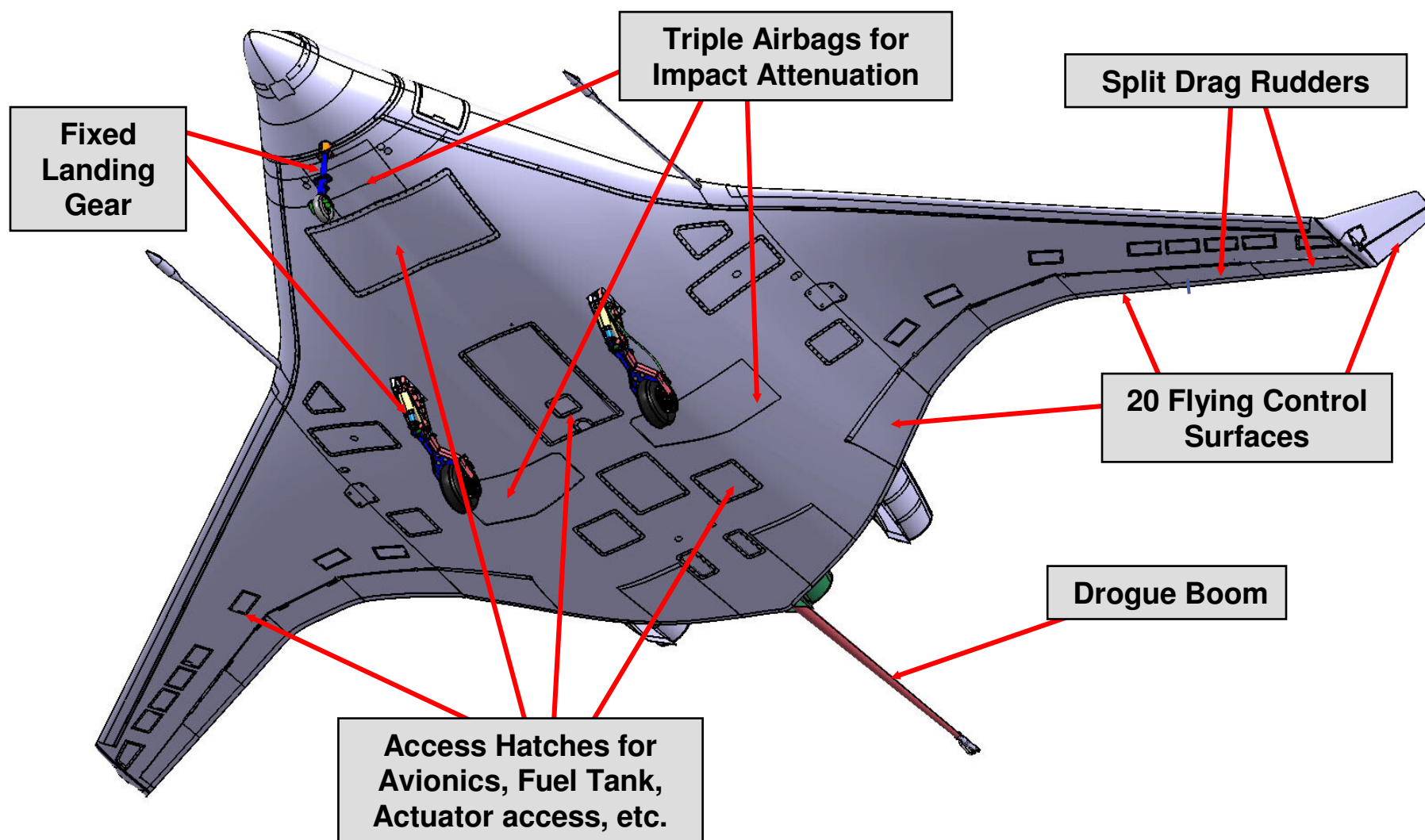


X-48B Configuration – Internal View





X-48B Configuration – Underside View



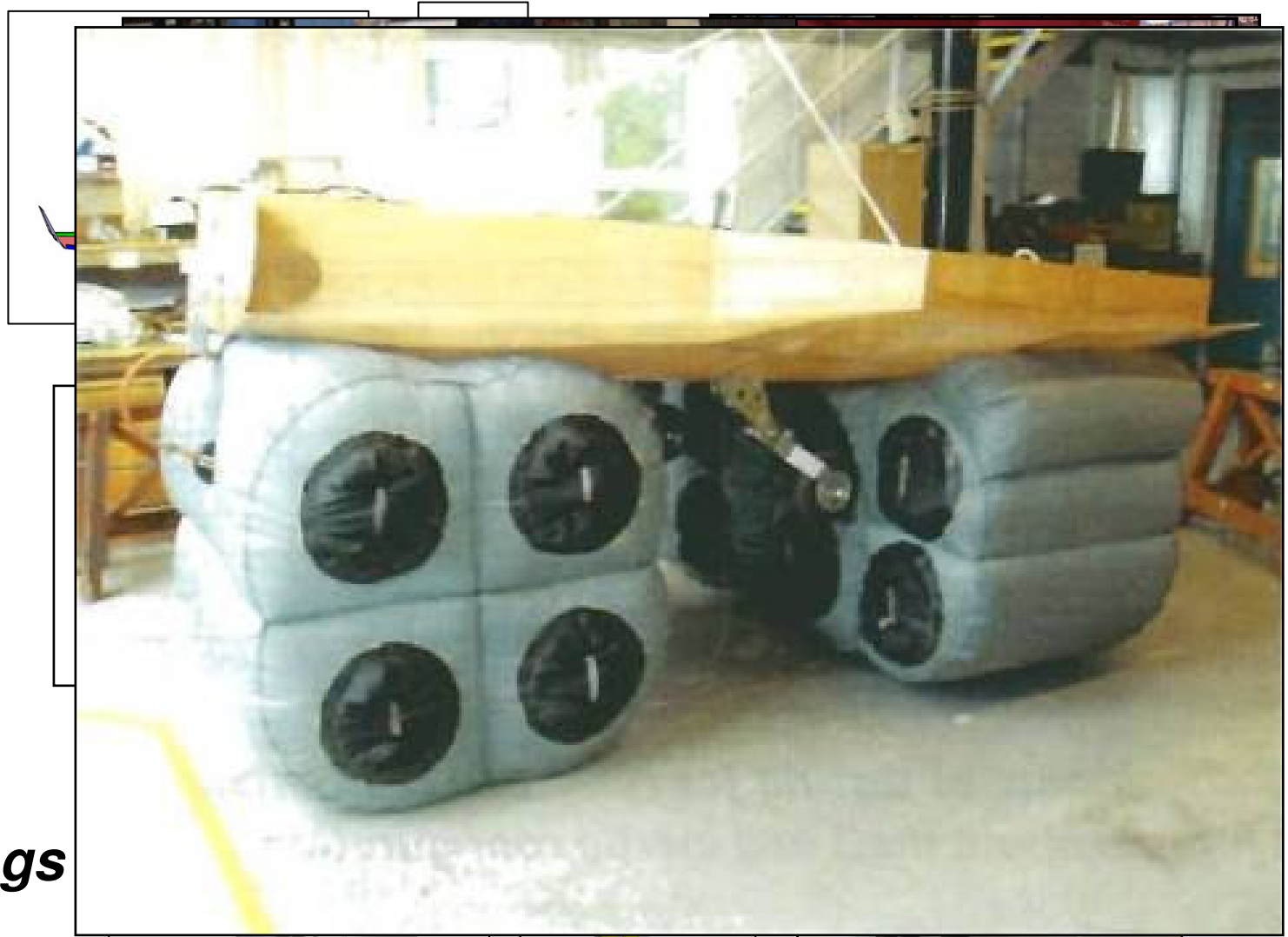


Recovery System

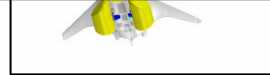
Drogue

Main

Airbags



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Spin Chute Testing



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Ground Control Station – Trailer



Fundamental Aerodynamics Program
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GCS – Pilot Station



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Subsonic Fixed Wing Project



Lakebed Operations



Subsonic Fixed Wing Project



X-48B Skyray 1st Flight Highlights



X-48B Flight Research Summary - I

- Twenty Flights completed in Blocks 1 & 2
 - 11 Flights w/ Slats Extended
 - Slats result in lower speeds and higher lift
 - 9 Flights w/ Slats Retracted
 - New Flight Control Laws / “1st Flight”
 - Envelope Expansion to Max Speed
- Highlights:
 - Test Maneuvers
 - Real-Time Stability Margins – Envelope Expansion
 - Automated Parameter Identifications (PID) – Freq Sweeps/Doublets
 - Steady Heading Sideslips - Simulate Cross-winds
 - Lazy-8s and Wind-up Turns
 - Airspeed Calibrations (Triangle method)
 - Approach to Stalls





X-48B Flight Research Summary - II

- Ten Flights completed in Block 3 (all slats extended)
- Highlights:
 - Test Maneuvers
 - Real-Time Stability Margins
 - Automated Parameter Identifications (PID) – Freq Sweeps/Doublets
 - Steady Heading Sideslips - Simulate Cross-winds
 - Lazy-8s and Wind-up Turns
 - AOA Maneuvers above C_L max





High Angle of Attack Maneuver



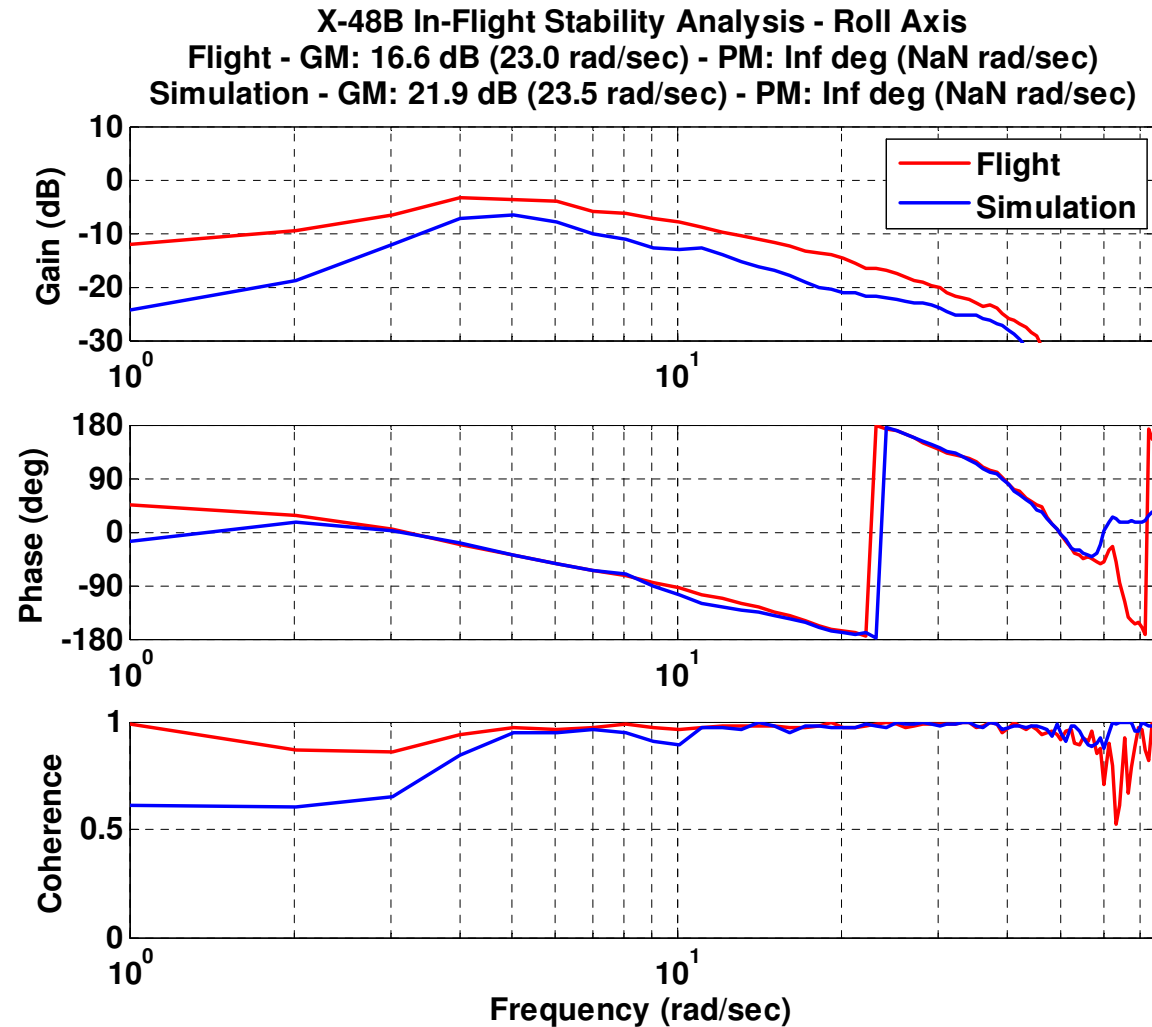


Real Time Stability Margin (RTSM)

- In-Flight Stability has a long history at NASA Dryden Flight Research Center
 - Application to a wide variety of flight programs
X-29, X-36, X-43, X-45, NF-15B 837
 - Method is motivated by inability to break loops on unstable aircraft
- Proprietary dynamic inversion based flight control
 - Numerous options for on-board excitations
- Excitation parameters and command sent via telecommand from GCS
 - Selectable injection points
 - Selectable waveforms
 - Selectable magnitudes



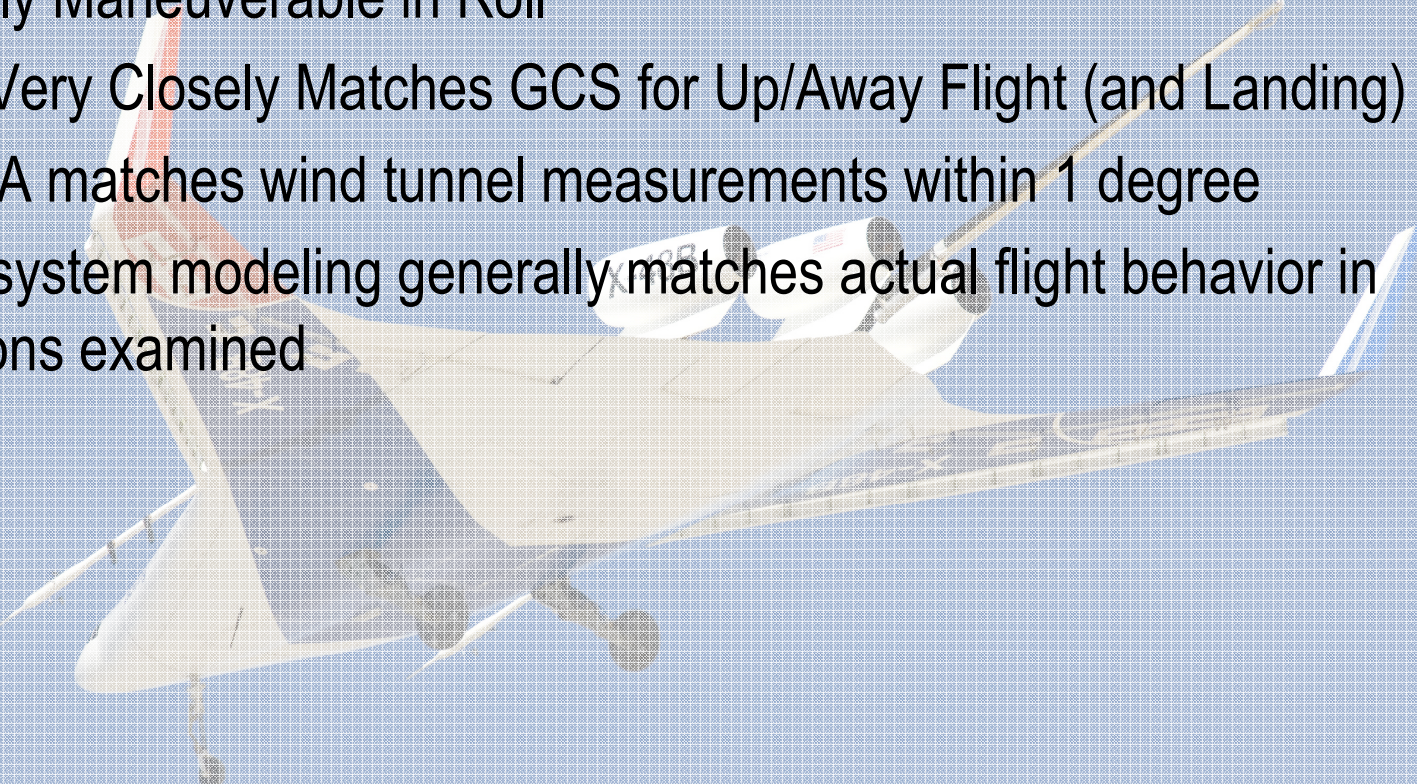
RTSM Results



From: Regan, Christopher, "In-Flight Stability Analysis of the X-48B Aircraft," AIAA Paper AIAA-2008-6571, AIAA Atmospheric Flight Mechanics Conference and Exhibit, Honolulu, Hawaii, Aug. 18-21, 2008.



X-48B Initial Flight Research Results

- Extremely Maneuverable in Roll
 - Aircraft Very Closely Matches GCS for Up/Away Flight (and Landing)
 - Stall AOA matches wind tunnel measurements within 1 degree
 - Control system modeling generally matches actual flight behavior in the regions examined
- 
- A photograph of the X-48B aircraft in flight. The aircraft is a white, delta-wing configuration with a canard and a large, curved leading edge. It is shown from a side-on perspective, flying against a blue sky. The aircraft's wings are swept back, and the canard is visible at the front. The aircraft is in a steep climb, with its nose high and its wings angled upwards.
- Flight Control Design is Very Robust
 - Overall, the Aircraft Flies Extremely Well
 - Despite no peripheral cues (2-D only) / no seat-of-the-pants



X-48B What's Next for the Future

- Current plan to finish 40+ flights in early CY2009
 - Follow-on Testing planned to continue thru FY2010
- Continue Phase 3/4 :
 - Stalls / High Alpha / Engine Out Assessment
- Phase 5/6:
 - Departure Resistance - Limiter Assaults / High Beta
- Potential new Engine Design
 - More Efficient = More Duration
- Low Noise Modifications
- Intelligent Flight Controls



Questions?

